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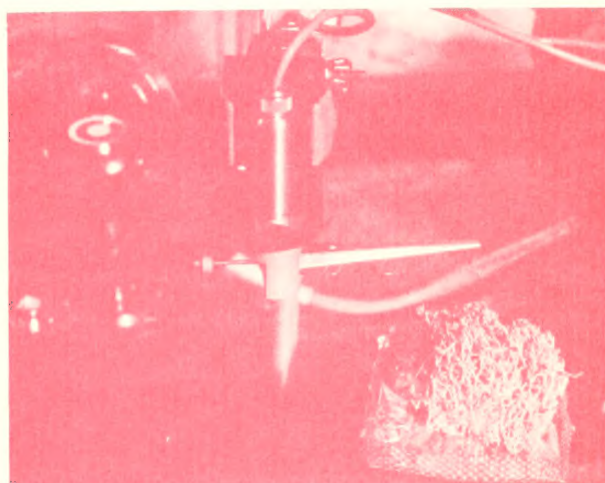
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TIMELAG AND EQUILIBRIUM MOISTURE CONTENT OF REINDEER LICHEN

R.W. Mutch and O.W. Gastineau

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401

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ABSTRACT

Almost one-half of the 220 million acres in central Alaska is covered with tundra, a highly flammable fuel complex. Reindeer lichen (*Cladonia* spp.), one component of tundra, was collected near Fairbanks, Alaska, for adsorption and desorption laboratory tests of timelags below fiber saturation and equilibrium moisture contents. Time responses recorded for five timelag periods differed widely, increasing over periods 2 and 3, then decreasing. Semilogarithmic plots for reindeer lichen did not fit the strictly linear form predicted by the timelag equation. Average desorption timelag was 1.7 times faster than the adsorption timelag. Equilibrium moisture content data indicated a slight hysteresis loop between adsorbing and desorbing conditions. The National Fire-Danger Rating transitional moisture curve approximates the equilibrium moisture content of reindeer lichen as determined in this study.

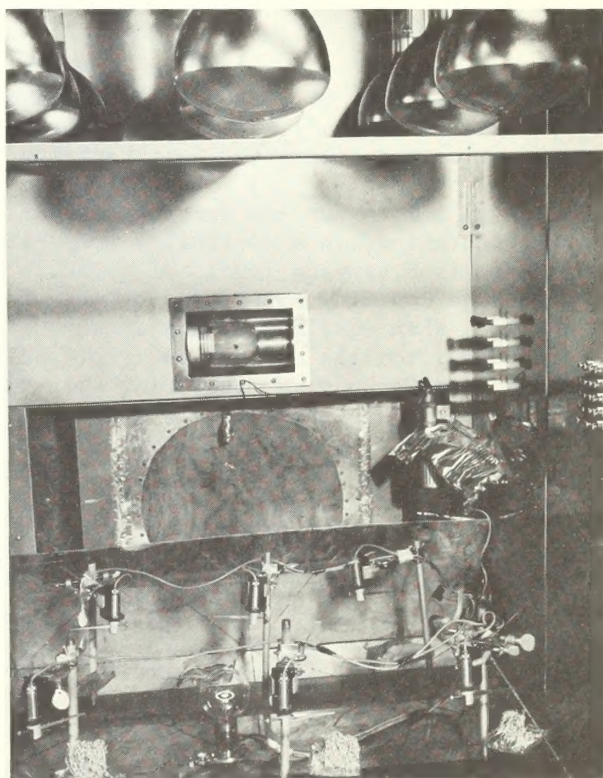
INTRODUCTION

An understanding of fine fuel moisture responses is necessary for effective interpretation and application of the National Fire-Danger Rating System. As improvements are made in the National Fire-Danger Rating System, knowledge of the moisture responses of common wildland fuels in the United States becomes increasingly important. This report summarizes results of laboratory tests to determine adsorption-desorption timelags below fiber saturation and equilibrium moisture contents of reindeer lichen, (*Cladonia* spp.). The fuel tested was collected in the vicinity of Fairbanks, Alaska, in August 1967. Byram¹ described the usefulness of timelag in comparisons of the drying characteristics of forest fuels. He defined desorption timelag as the time required for a fuel to lose 63.3 percent of its initial moisture content above equilibrium (or to lose $1 - \frac{1}{e}$ of its moisture content above equilibrium where e is the base of natural logarithms). Under adsorbing conditions, timelag is the time required for a fuel to gain 63.3 percent of the initial moisture content below equilibrium. Equilibrium moisture content is the moisture level finally attained that is uniformly present in fuels exposed in an atmosphere of fixed temperature and humidity; this occurs when vapor pressure in the fuel equals vapor pressure in the atmosphere.

METHODS

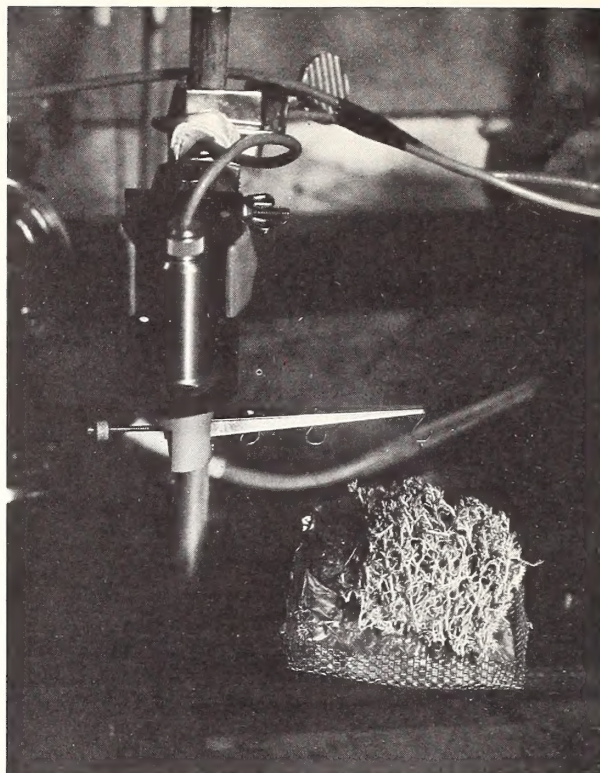
Intact sections of lichen fuels were placed in an environmental chamber for the duration of adsorption and desorption timelag tests (fig. 1). For adsorption tests, the temperature was kept constant at 80°F. while the humidity was stepped from 20 to 90 percent. For desorption tests, the temperature was held at 80°F. while humidity

Figure 1.--Reindeer lichen samples suspended on microscale transducers in environmental chamber. The solar radiation lamps in the top of the compartment were not used in these tests.



¹George M. Byram. An analysis of the drying process in forest fuel material. (Paper presented at the Int. Symp. on Humidity and Moisture, Wash., D.C., May 20-23, 1963.)

Figure 2.--Reindeer lichen sample and microscale transducer. Sample was placed on aluminum foil sheet in 3- by 4-inch weighing basket.



was dropped from 90 to 20 percent. Samples were continuously weighed on microscale transducers (fig. 2). Timelags for the five drying periods were determined from adsorption and desorption weight-change traces.²

The adsorption and desorption equilibrium moisture contents of reindeer lichen were determined in a controlled temperature cabinet. Six salt solutions were used to establish varying levels of relative humidity. Temperature was held constant at 80°F. and humidity was varied between 7 and 88 percent. Samples were weighed continuously. When equilibrium was reached at each humidity level, several samples were withdrawn from the cabinet and their moisture contents measured in a vacuum oven at 122°F. for 24 hours.³ Dew point was monitored in the equilibrium moisture content cabinet using a Cambridge dew hygrometer.

RESULTS

In a given timelag period, response times varied considerably among replicates, especially during adsorption tests (table 1). Nor are we the first to observe variability within a given timelag; Kübler,⁴ for instance, reported that the response times of equal-sized wood samples of the same species vary by one order of magnitude. Also of interest are the variations in response times we recorded for the five timelag periods (fig. 3). Our studies of reindeer lichen showed that timelag increases

²Drying periods were defined by the following percentages of moisture change between initial and equilibrium moisture content: 63.3, 86.5, 95.0, 98.1, and 99.3.

³Vacuum drying at 122°F. was comparable to regular ovedrying at 221°F.

⁴H. Kübler. Studien über die Holz Feuchtebewegung. Holz als Roh-und Werkstoff. 15: 453-468. 1957.

Table 1.--Adsorption and desorption timelag constants of *Cladonia*.
Adsorption conditions: 80°F. and humidity step change from
20 to 90 percent. Desorption conditions: 80°F. and
humidity step change from 90 to 20 percent

Timelag period	Adsorption replicates			Average timelag constant
	1	2	3	
	Minutes			Minutes
1	50	55	30	45
2	80	115	100	98
3	140	120	90	116
4	120	90	60	90
5	110	70	20	67
Average	100	90	60	83

Timelag period	Desorption replicates			Average timelag constant
	1	2	3	
	Minutes			Minutes
1	50	42	42	43
2	85	53	45	61
3	95	67	48	70
4	45	43	35	41
5	30	20	25	25
Average	61	45	39	48

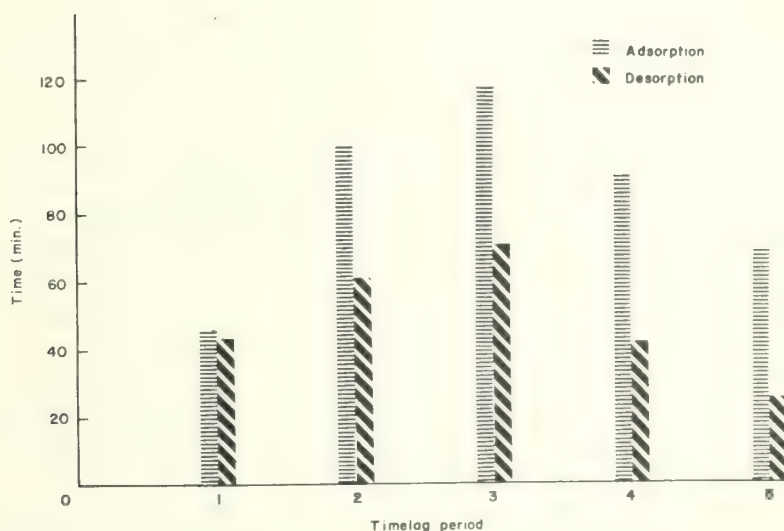


Figure 3.--Adsorption and desorption timelag periods of reindeer lichen.

over periods 2 and 3, then declines for remaining periods. We have observed this trend in tests of other fuels also. Because diffusivity is moisture dependent, the quadratic term in the diffusion equation prevents a simple mean value approximation from being made.⁵ Adsorption and desorption curves for reindeer lichen show fuel responses to humidity step changes at 80°F. (figs. 4 and 5). The equilibrium moisture content results are shown in table 2 and plotted in figure 6.

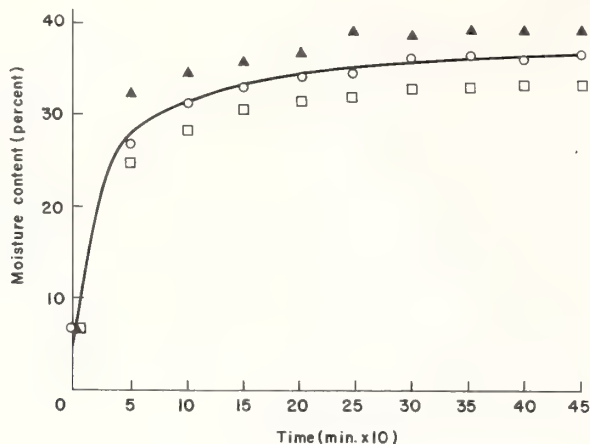


Figure 4.--Adsorption curve of reindeer lichen for a humidity step change of 20 to 90 percent at 80°F. Symbols represent replicates.

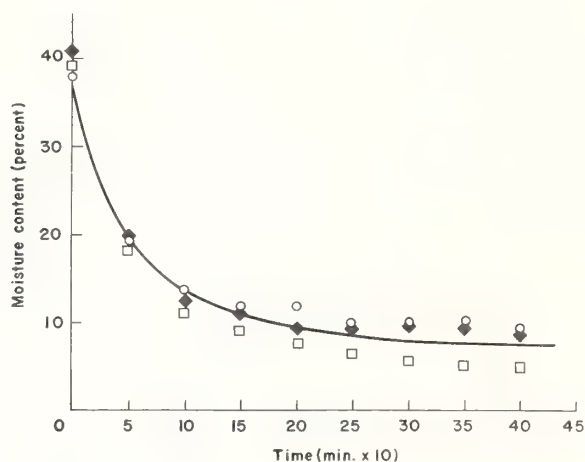


Figure 5.--Desorption curve of reindeer lichen for a humidity step change of 90 to 20 percent at 80°F. Symbols represent replicates.

⁵M. A. Fosberg, R. W. Mutch, and H. E. Anderson. Laboratory and theoretical comparison of desorption in ponderosa pine dowels. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo. (In preparation.)

Table 2.--Adsorption and desorption equilibrium moisture contents of reindeer lichen

Salt solution	Dry bulb ¹	Relative humidity	Average adsorption moisture content	Dry bulb	Relative humidity	Average desorption moisture content
	<u>°F.</u>	<u>Percent</u>	<u>Percent</u>	<u>°F.</u>	<u>Percent</u>	<u>Percent</u>
P ₂ O ₅				80	7.2	3.9
LiCl	80	16	6.5	80	15.0	7.5
MgCl ₂	80	33	10.2	80	35.0	11.4
Mg(NO ₃) ₂	80	53	11.6	80	56.0	12.6
NaCl	80	68	16.6	80	68.0	16.9
KNO ₃	80	88	20.8			

¹Dry bulb temperature was controlled at 80°F. + 1°.

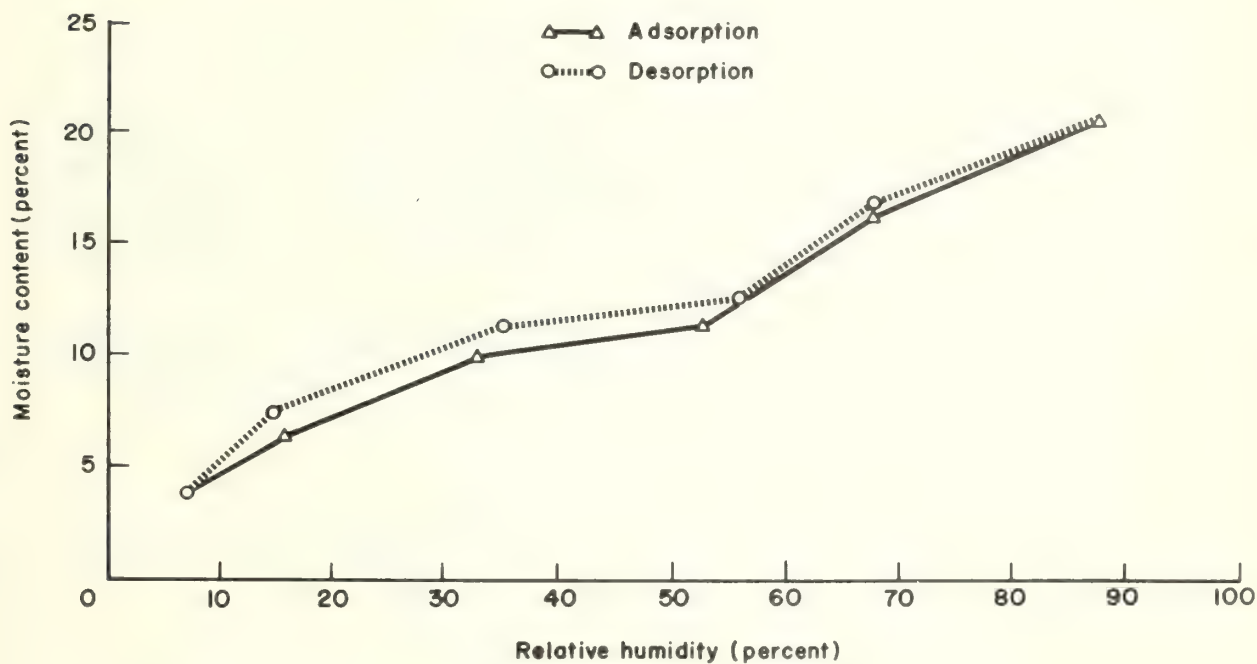


Figure 6.--Adsorption and desorption equilibrium moisture contents of reindeer lichen at air temperature of 80°F.

DISCUSSION

Timelag is a parameter characteristic of all physical and chemical processes that occur at an exponentially decreasing rate.⁶ The question arises as to how closely the process of either adsorption or desorption of moisture in natural fuels approximates an exponential function. Our tests on reindeer lichen showed that response times varied widely for the five timelag periods; time increased over the second and third periods, then decreased. Nelson stated that a plot of E versus time on semilogarithmic graph paper should be linear if the following timelag equation is obeyed:

$$\frac{\bar{m} - m_e}{m_o - m_e} = E = Ke^{-\frac{t}{\tau}}$$

where:

\bar{m} = average moisture content of fuel

m_e = equilibrium moisture content

m_o = initial moisture content

E = fraction of total evaporable moisture remaining
in the fuel at time t

K = a dimensionless constant for any given fuel shape

e = base of natural logarithms, 2.718

t = time

τ = timelag

Plots of E versus time for adsorption and desorption runs of reindeer lichen are shown in figure 7. As Nelson⁷ found with sawdust, wood, and paper samples, our experimental curves for reindeer lichen were curvilinear rather than strictly linear as predicted by the timelag equation. Where Nelson's semilogarithmic plots fell into three distinct regions, reindeer lichen data plotted into two straight-line portions with differing slopes.

Although the duration of the timelag periods varied, the variances do not negate the practical application of the timelag concept. Observed deviations in timelag do not appear to be significant in terms of general National Fire-Danger Rating applications.

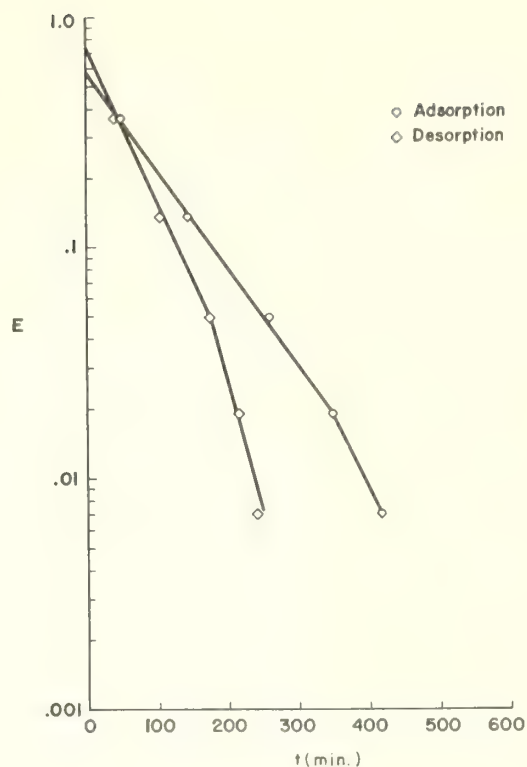
The average desorption timelag for reindeer lichen was 1.7 times faster than the adsorption timelag. Simard,⁸ in comparing the average rates of wetting and drying twig samples above fiber saturation, found that drying was about 1.4 times as fast as wetting. This difference he laid to the added diffusion potential of evaporation during the drying process.

⁶Ralph M. Nelson, Jr. Some factors affecting the moisture timelag of woody materials. USDA Forest Serv. Res. Pap. SE-44, 16 p., illus. 1969.

⁷Ibid.

⁸A. J. Simard. The moisture content of forest fuels. II: Comparison of moisture content variations above the fibre saturation point between a number of fuel types. Forest Fire Res. Inst. Inform. Rep. FF-X-14, 47 p., Ottawa, Ontario. 1968.

Figure 7.--Average adsorption and desorption curves of reindeer lichen at 80° F.; adsorption condition was a relative humidity step change from 20 to 90 percent; desorption condition was a relative humidity step change from 90 to 20 percent. The fraction of total evaporable moisture in the sample, E , was plotted against time.



The equilibrium moisture content data indicated a slight hysteresis loop between adsorbing and desorbing conditions. Reindeer lichen data (averages of the adsorption and desorption moisture content values) were plotted with the National Fire-Danger Rating transitional and cured moisture curves and the equilibrium moisture content data in the "Wood handbook."⁹ All data used were based on an air temperature of about 80°F. The National Fire-Danger Rating transitional moisture curve comes closest to approximating the equilibrium moisture content of reindeer lichen determined by this study (fig. 8).

Field inspection in Alaska showed that lichens become dry and brittle following exposure to direct sunlight. Insolation heats fuel surfaces and is important to determinations of moisture content in living reindeer lichen. Future tests will include insolation as an influencing factor on equilibrium moisture content and timelag.

⁹U.S. Dep. Agr., Forest Serv. Wood handbook. Agr. Handb. 72, 528 p., Forest Prod. Lab., Madison, Wis. 1955.

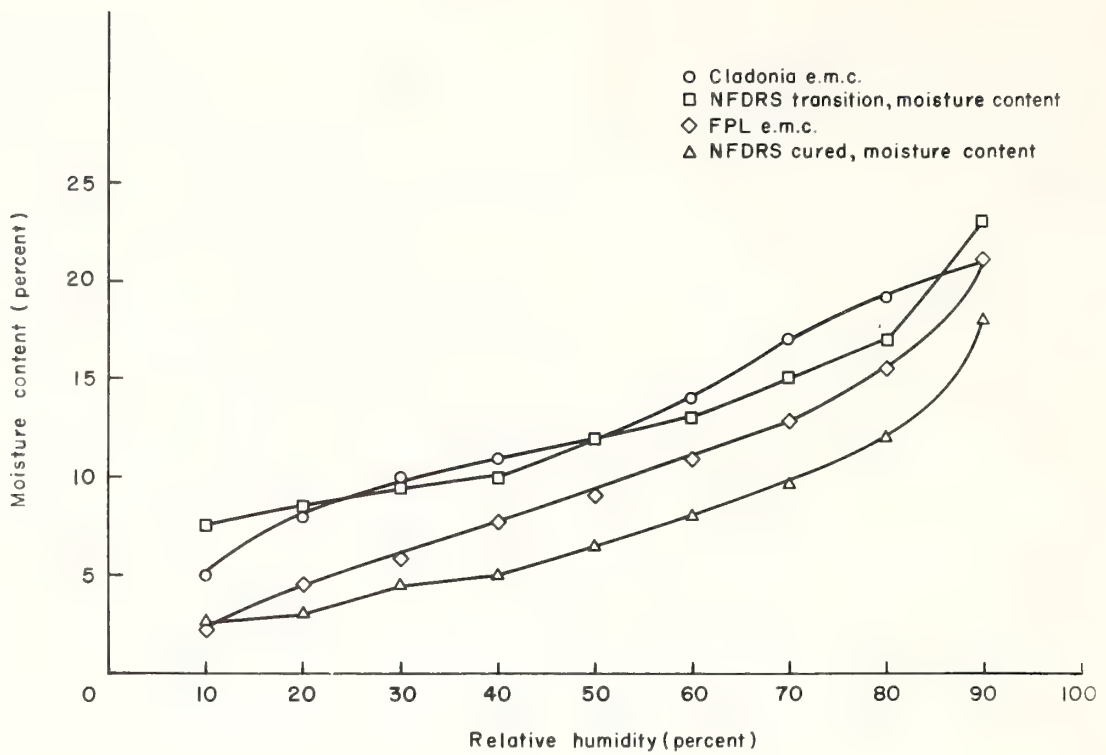


Figure 8.--Equilibrium moisture content of reindeer lichen compared with National Fire-Danger Rating System's moisture content data and Forest Products Laboratory's equilibrium moisture content data.

MUTCH ROBERT W. and GASTINEAU ORVAL W. JR.

1970. Timelag and equilibrium moisture content of reindeer lichen.
USDA Forest Serv. Res. Pap. INT-76, 8 p., illus.

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